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Easily reversible memory switching in Ge–As–Te glasses

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Abstract. Electrical switching behaviour of melt-quenched $Ge_{10}As_{45}Te_{45}$ and $Ge_{10}As_{40}Te_{50}$ glasses have been studied in the I–V mode, using a constant current source with incremental current steps. The samples are found to stay in the high-resistance OFF state up to a critical voltage V_c (corresponding to a critical current I_c). Above V_c, the sample switches to a low-resistance ON state with a stable negative resistance region, and lock-on to this state even if the current is reduced to zero. If the compliance voltage is turned off and switched on again, the switching transient introduced is found to reset the glasses back to the OFF state. The samples are found to switch again. The switching–resetting–switching cycle is repeated 50 times, with ±10% variation in the switching voltages.

1. Introduction

The current-controlled electrical switching (from the high-resistance OFF state to the conducting ON state) in chalcogenide glassy semiconductors is threshold or memory type [1–9]. In glasses exhibiting memory switching, the conducting ON state established during switching is retained even if the current is reduced to zero. Glasses which show threshold behaviour, on the other hand, switch back *from* the ON state to the OFF state if the current is reduced below a 'holding' value [1, 9]. Memory switched samples may also be reversed back to the high-resistance OFF state by the application of a current or light pulse [1, 9]. The phenomenon of resettable memory switching in chalcogenide glasses has attracted certain interest in the context of read mostly memory (RMM) applications which require mostly reading and occasional rewriting [10, 11].

In this paper we report an easily reversible memory switching in melt-quenched $Ge_{10}As_{45}Te_{45}$ and $Ge_{10}As_{40}Te_{50}$ glasses which indicates that these samples are well suited for RMM applications.

2. Experimental

Bulk homogeneous $Ge_{10}As_{45}Te_{45}$ and $Ge_{10}As_{40}Te_{50}$ glasses have been prepared by melt quenching. Samples of different thicknesses (0.18–0.32 mm) polished initially with a coarse emery (100 grade) and subsequently with a fine emery (400 grade) paper have been used for electrical switching studies undertaken in a custom built IBM PC based set-up [12]. The samples are held in special holder, between a point contact top electrode and flat plate bottom electrode, using a spring loading mechanism. A constant current is passed through the sample and the voltage developed is measured. The experimental details are described elsewhere [12].

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3. Results and discussion

3.1. CCNR (current-controlled negative resistance) with memory

Figure 1 shows the I–V characteristics of as-quenched $Ge_{10}As_{45}Te_{45}$ and $Ge_{10}As_{40}Te_{50}$ glasses where it can be seen that initially (in the high-resistance OFF state) the voltage across the samples varies ohmically with current (region OA in figure 1). Near a critical voltage V_c (corresponding to a critical current I_c) the characteristic becomes nonlinear (region AB). At V_c the samples exhibit a negative resistance behaviour (region BC) which leads to a low-resistance ON state (region CD). In the ON state the I–V characteristic is nearly linear and the dynamic resistance is almost zero. The samples remain in the ON state if the current is reduced to zero (region DO). On increasing the current again, the sample retraces the ON state characteristics. Under the zero bias condition the sample stays in the ON state.

It is interesting to note that the memory switching in Ge–As–Te samples is easily reversible. If the compliance voltage is turned off in the ON state and switched on again, it is found that the samples revert back to the initial high-resistance OFF state and the samples can be switched again. In the present study, switching, resetting and switching again of Ge–As–Te samples have been carried out for

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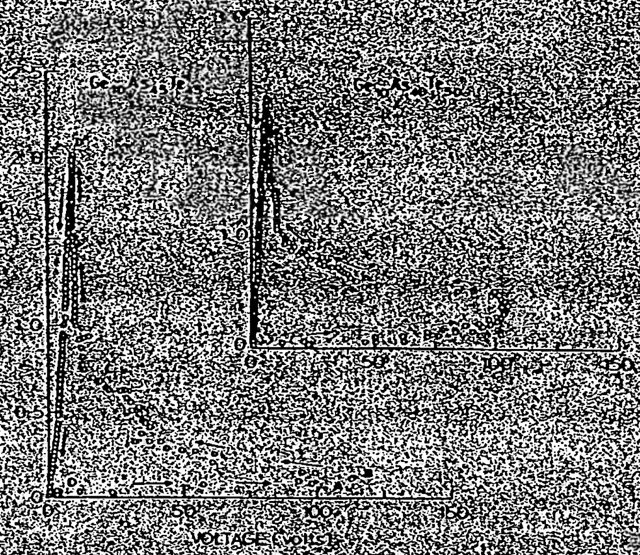

Figure 1. The electrical switching characteristics of $Ge_{10}As_{45}Te_{45}$ and $Ge_{10}As_{30}Te_{60}$ glasses.

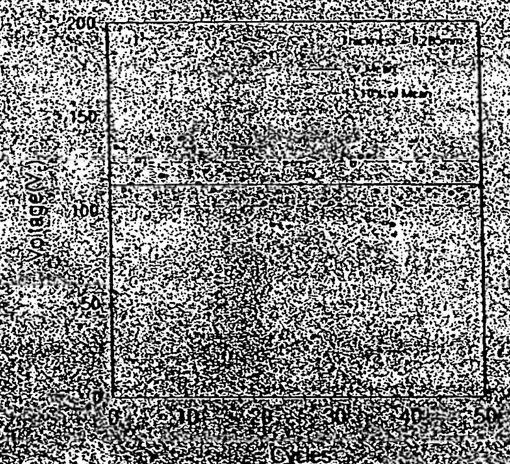

Figure 2. Typical variations in the measured values of the switching voltage of $Ge_{10}As_{45}Te_{45}$ with the switching cycles.

50 cycles and the characteristics are found to be repeatable with ±10% variation in the switching voltages (figure 2).

Figure 3 shows a schematic diagram of the constant current source used in the switching experiments. Here the resetting of the memory state in the Ge–As–Te samples is due to the transient generated while turning on the compliance voltage of the constant current source unit with transistor Q_1 also on. The transient across the sample has been captured using a Tektronix TDS 320 storage oscilloscope. Figure 4 shows the 190 V, 20 mA, 300 ns transient produced which is responsible for resetting. The transient is avoided by turning transistors Q_1 and Q_2 off. Under this condition the samples remain in the ON state irrespective of current condition.

Switching studies conducted on Al–Te [8], As–Te [7] and Al–As–Te [9] glasses using the same experimental set-up reveal that these samples also exhibit memory switching. However, these samples do not revert back to initial high resistance state because of the transient discussed above. External resetting by the application of 100 mA and 10 ms pulse is found to be required for these samples. The present studies clearly indicate that the memory state in Ge–As–Te samples is easily resettable compared to other chalcogenide glasses investigated. Hence, memory switching Ge–As–Te samples may be more suitable for read-mostly memories.

It is interesting to compare memory switching behaviour and thermal parameters of As–Te and Ge–As–Te glasses. The crystallization temperature T_c, melting temperature T_m and electrical switching field E_{th} of As–Te glass are 195 °C, 470 °C [13] and 4.08 kV/cm respectively. T_c, T_m and E_{th} of $Ge_{10}As_{45}Te_{45}$ glass are 273 °C, 375 °C [14] and 5.4 kV/cm respectively. The crystallization temperature of $As_{40}Te_{60}$ glass is clearly lower than that of $Ge_{10}As_{45}Te_{45}$. This is reflected in the lower switching field of the As–Te sample compared to Ge–As–Te sample. The resetting of memory switched samples involves local melting and solidification of the conducting crystalline channel. The lower melting temperature of $Ge_{10}As_{45}Te_{45}$ compared to $As_{40}Te_{60}$ is consistent with the easier resetting observed in these materials.

3.2. Temperature dependence of switching voltage of Ge–As–Te glasses

The temperature dependence of the I–V characteristics is an important factor in considering a switching material for [illegible]

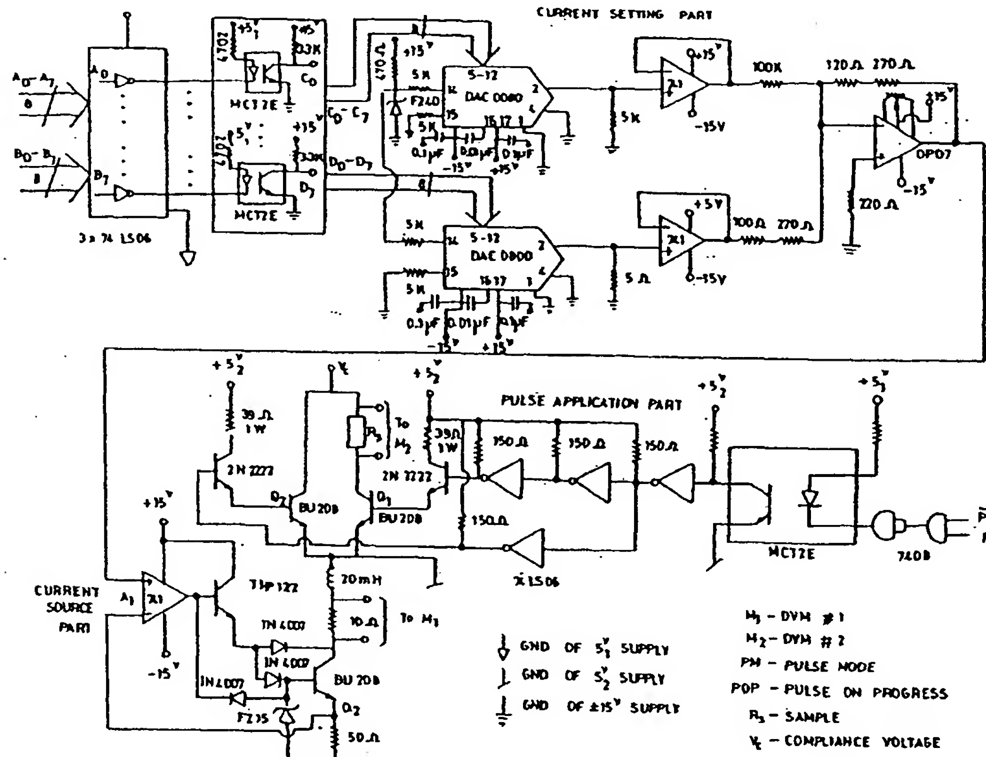

Figure 3. Schematic diagram of the constant current source unit used in the present study.

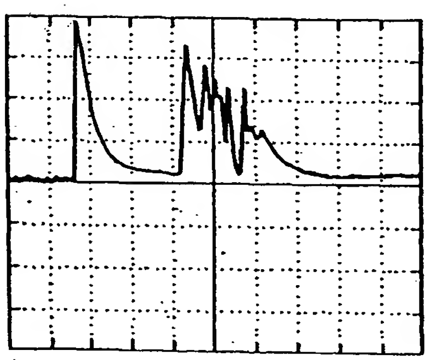

Figure 4. Transient produced during switching on the compliance voltage which is responsible for resetting; horizontal scale, 250 ns/division; vertical scale, 50 V/division.

information storage applications. In the present study, the effect of temperature on the current–voltage characteristic and switching behaviour of $Ge_{10}As_{45}Te_{45}$ and $Ge_{10}As_{40}Te_{50}$ glasses have been investigated. Usually, in memory switching materials, different samples of the same thickness are used to study the effect of temperature on the switching behaviour. In the present study, the same sample after resetting has been used for investigations at different temperatures.

Figure 5 shows the switching characteristics of $Ge_{10}As_{45}Te_{45}$ samples at different temperatures. It can be seen that the I–V characteristic becomes broader and the switching more sluggish at high temperatures. Similar temperature effects on switching have also been observed in $Ge_{10}As_{40}Te_{50}$ and in other chalcogenide glasses [8, 9].

It has been recently suggested by Prakash *et al* [8] that the variation of the switching voltage (or field) or chalcogenide glassy semiconductors with temperature can be given by

$$V_c^2 = c_1 \exp[C_2 k(T_g - T)/kT] \qquad (1)$$

where C_1 and C_2 are constants and T_g is the glass transition temperature of the material. Figure 6 shows the variation of $\log(V_c^2)$ with $(T_g - T)/T$ for $Ge_{10}As_{45}Te_{45}$ glass obtained in the present studies. It can be seen that the temperature dependence of switching voltages in $Ge_{10}As_{45}Te_{45}$ glasses obeys equation (1).

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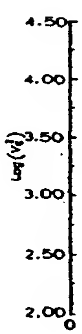

Figure 6. $Ge_{10}As_{45}$

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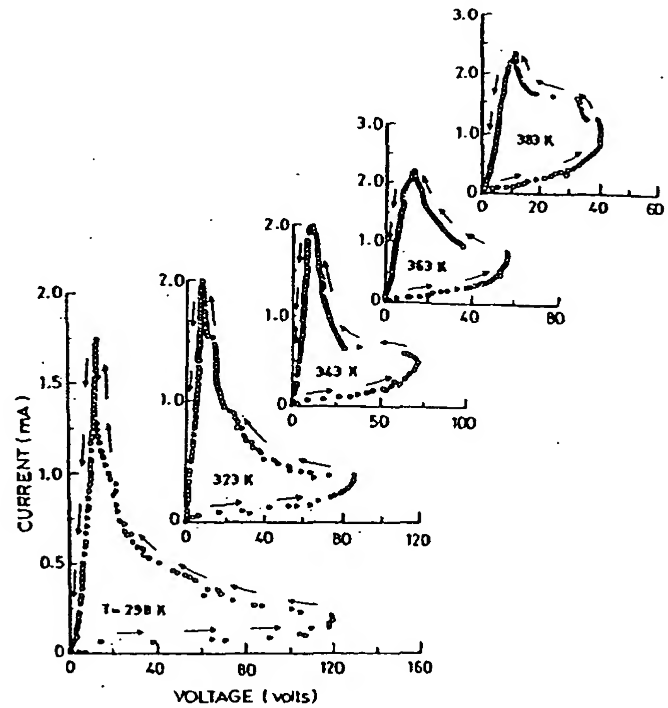

Figure 5. The I–V characteristics of $Ge_{10}As_{45}Te_{45}$ glass at different measurement temperatures.

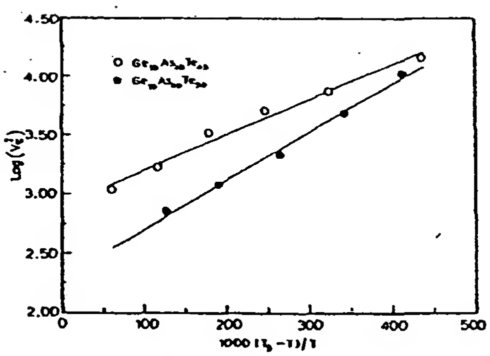

Figure 6. Typical plot of $\log(V_c)$ versus $(T_g - T)/T$ for $Ge_{10}As_{45}Te_{45}$ and $Ge_{10}As_{40}Te_{50}$ samples.

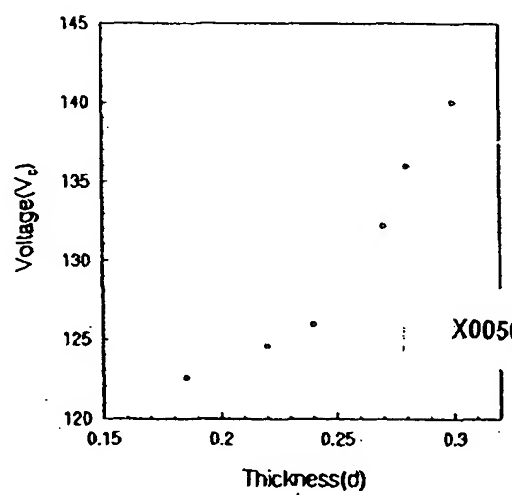

Figure 7. The variation of V_c with sample thickness d for $Ge_{10}As_{45}Te_{45}$.

3.3. Effect of sample thickness

The overall features of the I–V characteristics of $Ge_{10}As_{45}Te_{45}$ are not altered by changes in sample thickness. However, the switching voltage V_c is found to increase with increasing sample thickness (in the range 0.18 to 0.32 mm) as indicated in figure 7. It has been suggested earlier that the switching voltage will vary as $d, d^{1/2}$ or d^2, depending on whether the mechanism responsible for switching is electronic, purely thermal, or based on carrier injection [15]. It is found in the present study that the variation of switching voltages with thickness does not fit with any of the suggested dependences. This indicates that the mechanism of switching in Ge–As–Te samples is complex and may involve both electronic and thermal processes.

4. Conclusion

Bulk melt-quenched $Ge_{10}As_{45}Te_{45}$ and $Ge_{10}As_{40}Te_{50}$ glasses show a current-controlled switching with memory. The memory state in these samples is found to be easily reversible which indicates that these samples may be suitable for read mostly memory (RMM) applications. The variation of the switching parameters with temperature and sample thickness is found to be similar to that exhibited by other chalcogenide glassy semiconductors.

Acknowledgments

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